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Simple Gravitational Lens Demonstrations

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A very nice article in the *American Journal of Physics* (*AJP*)[1] prompted us to find a simple way (appropriate for conceptual physics students) to illustrate some of the common features of gravitational lensing. Gravitational lensing is a celestial phenomenon that occurs when two or more objects at different distances from the Earth lie along the same line of sight in the sky. The observation of this effect, which produces distortions and apparent displacements of the object farthest from Earth in the alignment, was listed by Einstein in his famous 1915 paper[2] as one of three important tests of general relativity. In 1936, Einstein showed that if an observer and two pointlike stars fell exactly along the same line of sight, the observer would see a ring around a bright point[3] rather than a single star or two stars. This is illustrated in Fig. 1. Light from the furthest star would be bent by the "lens" into a ring (hence the name "Einstein ring").

It was more than 40 years after Einstein's prediction before a gravitational lensing event was observed.[4] Images of some confirmed gravitational lenses can be found on the Space Telescope Science Institute's (STScI) Web site[5] and other URLs.[6]

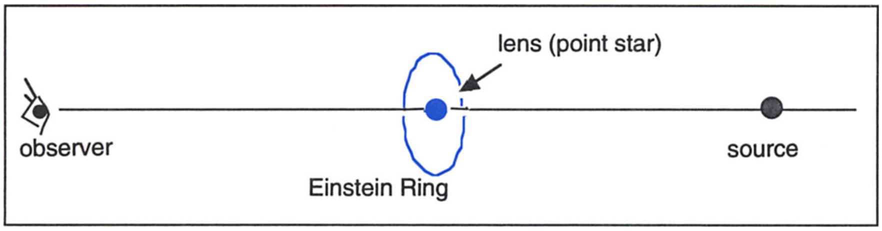

Fig. 1. Alignment of objects necessary for observation of an Einstein ring. Case of a point star for the lens is considered here; however, the lens can be a galaxy or cluster of galaxies as well.

Making the Simulator

Papers describing ways to optically simulate gravitational lensing events have appeared in *AJP*,[7] but the high-quality lenses described are labor-intensive to make and require expensive shop tools. Our inexpensive alternative to the high-quality gravitational lens simulator illustrates the effects of observer-lens-source alignment on image formation and can be made for under $1! All you'll need is a wineglass and hacksaw or glass file.

To make the gravitational lens simulator shown in Fig. 2, use the hacksaw or glass file to score the wineglass stem along a circumference of least cross section. Break the wineglass into two parts so that the break is parallel to the base of the glass and as smooth as possible. *Before breaking the glass, cover it with a towel, and wear gloves and/or goggles to avoid any mishaps.* If the break is not as smooth as you'd like, an acetylene torch can be used to "melt" the rough edges. (Our chemistry department helped us out.) It is important to use a wineglass with a cylindrically symmetric base and stem (no corners). This lens simulates the effect of the gravitational field of a point mass on light coming from a more distant source. This particular lens shape (profile) was derived using Einstein's 1936 calculation and Fermat's principle.[1] The properly derived lens profile should be logarithmic. Ours is not logarithmic, but is close enough for demonstration purposes (Fig. 3).

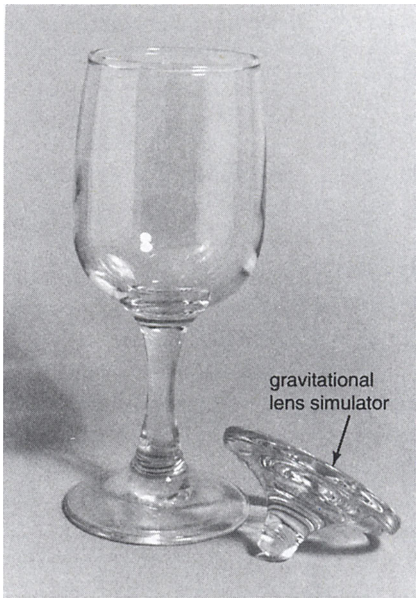

Fig. 2. Lens shown here was made from inexpensive wineglass, as described in the text.

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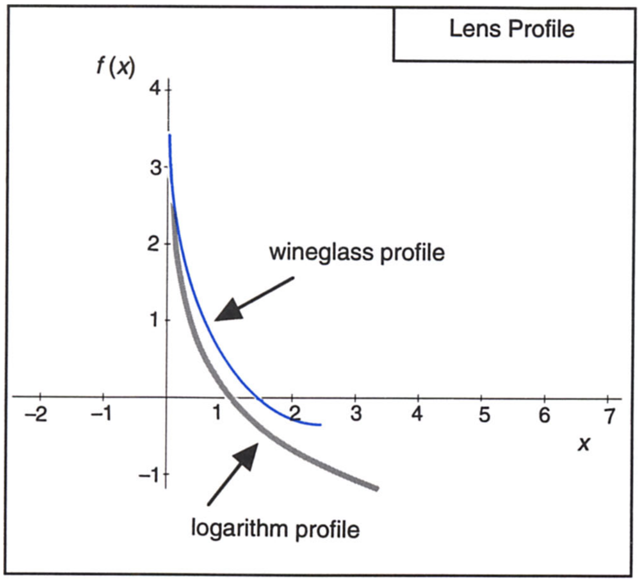

Fig. 3. Plot of –Ln(x) compared with wineglass profile. The logarithm profile is the correct profile to use to simulate a point mass lens, but a computer-controlled lathe is required to make such a lens simulator. The wineglass profile is close enough for demonstration purposes.

We use this lens to illustrate two common features of a gravitational lensing event.[8]

Demonstration 1: Observer-Source-Lens Separation and Ring Size

You'll need a light source (with an oriented-shaped filament if possible), lens simulator, optical bench and holders (optional), and screen.

Set up the light source, lens, and screen using the holders or your hands. Project the light from the source through the lens onto a screen. An Einstein ring will form on the screen. Note the dependence of ring diameter on source-lens separation and lens-screen separation. This dependence is derived in the analysis of the celestial phenomenon as well.[9] If you do not want to spend the time to set up the optical bench, a qualitative demonstration can be done using an overhead light bulb as the source and some smooth surface (e.g., wall, floor, hand) as the screen (Fig. 4).

Another interesting thing to try is this. Use a pin to prick a hole in a piece of black cardboard paper. Use this "pinhole camera" to look at the light coming from a portion of the ring. If the source has a filament with distinguishable shape to it, you'll be able to see that the ring is really the superposition of lots of filaments into a ring. Move the pinhole camera around the ring to verify this. The pinhole image of the center of the ring is also very interesting. You'll have to try it to find out what the image looks like.

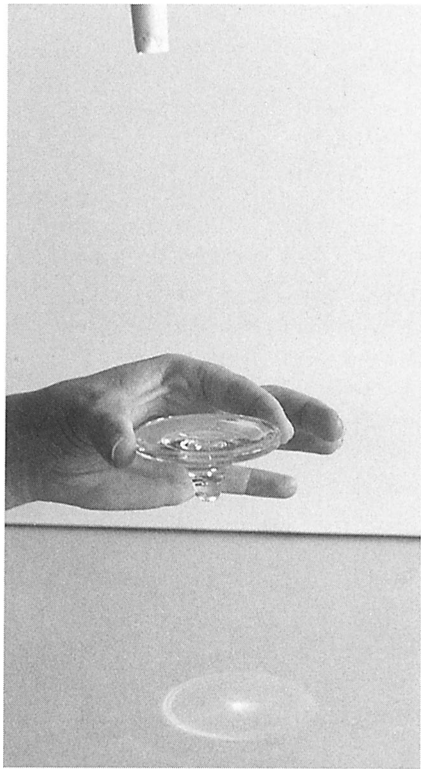

Fig. 4. Quick classroom demonstration used a pocket penlight as the source and hands to hold lens and light. Einstein ring is clearly visible on the paper.

Demonstration 2: Multiple Images

For this demonstration you will need white paper, a black pen, and the gravitational lens simulator.

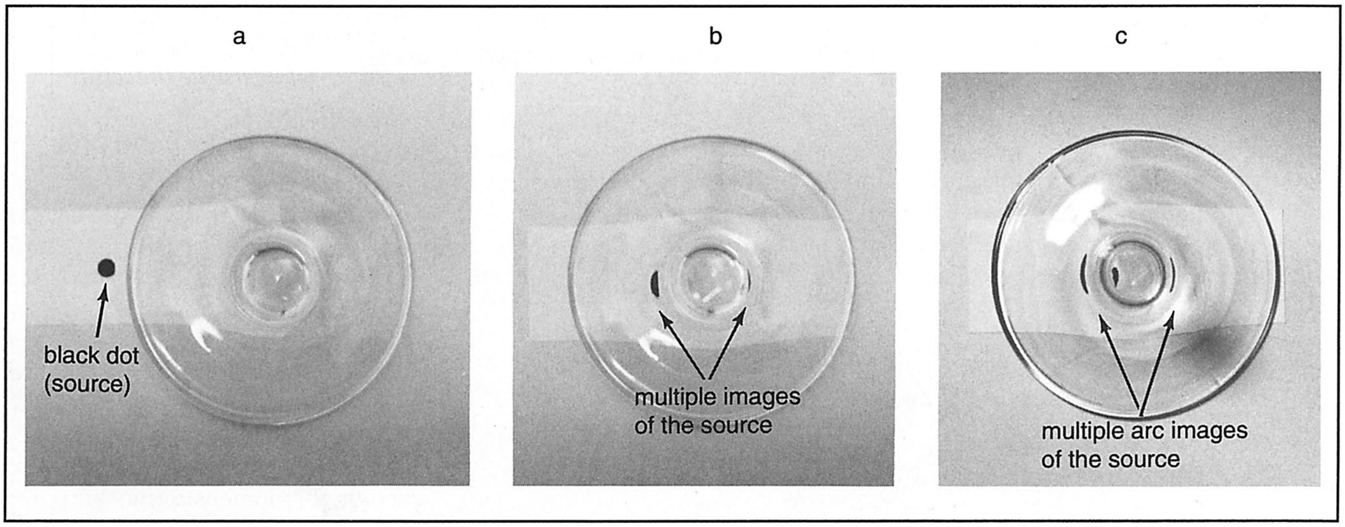

Fig. 5. Photo 5a shows lens simulator and black dot that serves as the more distant source. Gravitational lens simulations (5b, 5c) can be compared with actual images taken using radio and optical telescopes. For example, compare simulation 5c with the observation of MG1654+13 on STScI's Web site.[5]

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Draw a black dot about 5 mm in diameter on the white paper. Place the lens (flat side down) on the white paper. Move the lens slowly over the dot. Look "through" the lens to see the image of the black dot. Notice what happens to the black dot as it moves under the lens (Fig. 5). When the dot is near the outer edge of the lens only one image is seen. As the center of the lens and the dot grow closer, the image becomes more distorted until finally there are two images (arcs). Once the lens is centered on the dot, the Einstein ring is formed. This can be compared to images of confirmed gravitational lenses like those on STScI's Web site.[5] In addition to the images shown in Fig. 5 we have been able to produce three- and five-point images (Einstein cross) and various types of arcs using the lens simulator shown in this article. These sorts of images and the optics of gravitational lensing by point lenses are described by Blandford.[10]

Some introductory articles on gravitational lensing can be found in Ref. 11. Contemporary reviews of the significance of this phenomenon and the phenomenon of gravitational *micro*lensing (which we have not discussed here) are given in Ref. 12.

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